**APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS FOR RAILWAY TRACK MAINTENANCE AND RENEWAL MANAGEMENT**

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## Abstract

The associations working on transportation fields use available data to define the goals and target related with services or facilities purposes. Asset Management Systems (AMS) concept is important on transportation field and it cover facilities, infrastructure and superstructure components of the transportation systems. Costs of permanent way and its maintenance and renewal (M&R) are substantial and form a large part of the total infrastructure expenditure. Any reduction of these costs has a significant impact on the overall efficiency of the management of infrastructure. The process of determining whether, when, where and how to intervene and deciding on an optimum allocation of resources and minimising the cost is a very complex problem because: different track sections tend to behave differently under the effects of loading; decision processes for M&R works are closely interrelated technically and economically; decision-making for M&R plans is based on a large quantity of technical and economic information, extensive knowledge and above all experience. Due to the specific requirements of transportation applications and of the rather late adaptation of Geographic Information Systems (GIS) technology in transportation, research has been directed toward enhancing existing GIS approaches to enable the full range of capabilities needed in transportation research and management. In this study, stations, segments, railway network, maintenance and renewal works of Turkish State Railways were transferred into GIS environment and developed a data base and realised analysis.

Keywords: Geographic information systems (GIS); Track maintenance and renewal (M&R);
Asset management systems (AMS).
Topic Area: D4 Applied Geographical Information Systems

## 1. Introduction

The assets that consist of railway track components and facilities must be managed by using appropriate management systems and tools. Thus the term of asset management systems (AMS) was begun to use for realising efficient railways. Although a number of definitions are used for asset management, asset management is the systematic process of maintaining, upgrading, and operating physical assets cost effectively. With this definition, asset management is a decision making tool that creates a framework for both long and short term planning. Asset management systems should provide complete life cycle coverage, starting with the planning and continuing until replacement or reconstruction. Through the automation of the maintenance process as asset management tool can save time and provide accurate information on railway track. This will help managers use good data to make objective judgement in selective maintenance strategies (Wittwer, E., Bittner J., Switzer, A., 2002).

In the railway transportation system, geographic analysis is the key to making better decisions. Monitoring rail systems and railroads conditions, finding the best way to deliver goods and services, maintaining transportation networks, understanding these issues from a geographic perspective is crucial to deploying or spending resources wisely. Geographic Information Systems (GIS) can be used to determine the location of an event or asset and its relationship or proximity to another event or asset, which may be the critical factor leading to a decision about design, construction, or maintenance (J.R William, 1989).

## 2. Deterioration of track geometry

Standard track geometry parameters are gauge, alignment, superelevation (cross-level or cant), level and twist. Gauge is defined as the horizontal distance between two rails and is measured between the heads of the rails at the tight angels to the rails. The nominal gauge for tracks is 1435 mm, although a wide variety of other gauges are used around the world. Alignment is defined as the average of the lateral position of each rail to the track centreline. Alignment is measured separately for the left and right rail in a manner similar to the gauge. Superelevation is the difference in height between the two rails taken from a common datum. Level is defined as the average height of the two rails. The left and right levels are the vertical height of the left and right rails. Twist is defined as the difference in superelevation (cant) over a given length. In other words, if the wheels of railway cars having same loads are not at the same level then this defect is called as twist (White, D.L, July 1998).

Track condition is defined by the condition of its components and its geometry. These two groups of elements are closely interrelated within the complex process of track deterioration and restoration; if one is in poor condition this will contribute to the deterioration of the other, and if the components are in poor condition it will not be possible to correct the geometry efficiently. M&R activities must therefore be adjusted to match the age of the track. The model therefore distinguishes between “young”, “old” and “intermediate” track. The duration of each of these phases, and the lifetime of the track, will vary considerably depending on the characteristics of the track itself. Aside from the loads to which the track is subjected, the number and scale of maintenance operations will play an essential role.

The basic idea is that the behaviour of the track geometry of a certain segment, expressed by means of a certain geometry parameter, is monitored in time and, thus, captured (Figure 1). The green line shows the hypothetical deterioration of the track geometry if the track had been left to deteriorate without any maintenance input. On this line we can also distinguish three phases: the first phase, often referred to as "youth", occurs immediately upon (re) construction or completion of certain major renewal work and characterises rapid and substantial deterioration caused by the initial settlements of the track (Figure 1 marked with "a"). This period is also highly unpredictable and differs considerably from one track section to another. It is, therefore, very hard to model. The length of this period is fortunately quite short which diminishes the consequences of omission.

The second phase, which occurs once the track has been sufficiently stabilised, shows a more or less linear deterioration pattern. This kind of behaviour occurs during most of the track’s life-time (Figure 1, marked with "b").

The third period occurs in the latter part of the track’s lifetime and is characterised by a more and more rapid deterioration, which eventually even exhibits a more or less exponential form (Figure 1, marked with "c"). Normally, this is a situation which should never be allowed to happen under any circumstances, as it could affect the safety of traffic as well. This is avoided by applying certain appropriate M&R works at a much earlier stage, i.e. there is always a present maintenance threshold value (horizontal purple line) which, when reached, triggers certain M&R activity.

Based on this concept, measurement data within the normal (linear) part of the track behaviour are analysed. The track geometry behaviour is captured by calculating the trend line through the measured points and extrapolating it. Provided that the maintenance threshold has been set (purple horizontal line), the moment (or the tonnage) when this extrapolated line will reach the threshold is calculated, marking the moment when certain M&R activity, e.g. tamping, should be performed.

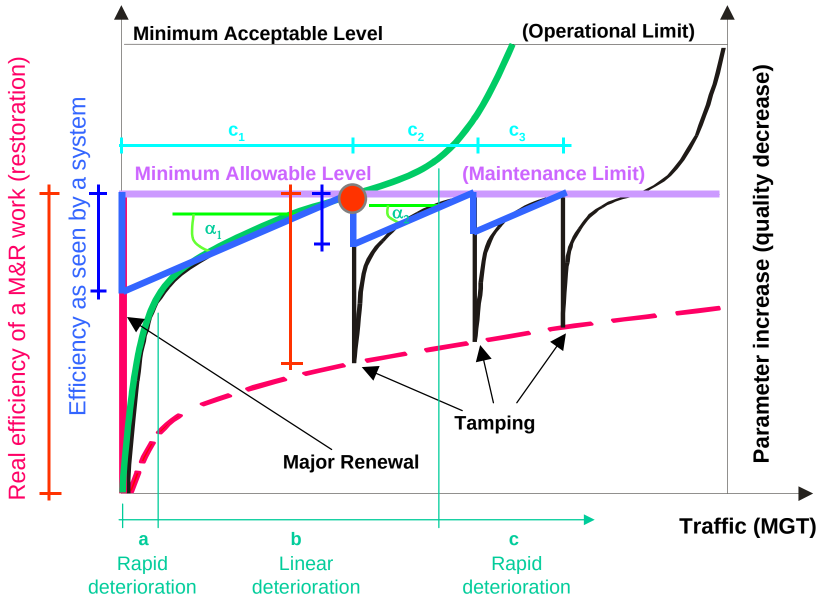



Figure 1. Analysis Principle applied on hypothetical track geometry deterioration

After tamping has been performed, the parameter value drops abruptly, i.e. the quality increases. In Figure 1 this is represented by the vertical distance marked with red (real parameter drops), or the blue vertical distance and vertical drops marked by the thick blue saw-tooth line (simulated parameter drops).

After the quality has been improved by tamping, the deterioration process will start again. However, several things will change over time as the track grows older. The first thing that changes is the efficiency of tamping, e.g. the intensity of the "vertical drop". This can be observed by looking at the line showing the "real behaviour" of the track (red vertical dimensioning line) or by looking at the simulated linear line (thick blue saw-tooth-like one). But it becomes even clearer from the dashed red line which shows this change over time. Another thing that changes is the "deterioration rate", i.e. the slope of the line defined by measured points (represented by green angle marked with $\alpha_1$ & $\alpha_2$). Both of these two events have their impact on the required tamping frequency, which becomes higher and higher, i.e. the time period between two tamping works (tamping cycle) becomes shorter and shorter. Eventually, the tamping frequency becomes so high that it no longer makes sense to tamp. However, action definitely needs to be taken, i.e. some other M&R activity like ballast renewal (Jovanovic, S., Korpanec, I., August 2000).

## 3. Track maintenance and renewal

Comfort, safety, efficiency, reliability and transit times are important factors for a transportation system. If railways are wanted to be compatible with the other transportation systems, these important parameters must be ensured at minimum cost levels. The process of determining whether, when, where and how best to intervene and deciding on an optimum allocation of resources, minimising the costs at the same time, is a very complex problem because:

- different track sections tend to behave differently under the effects of loading;
- decision-making processes for M&R works are closely interrelated technically and economically;

Decision-making for M&R plans is based on a large quantity of technical and economic information, extensive knowledge and above all experience. Track maintenance means the total process of maintenance and renewal (M&R) required ensuring track safety and quality standards at minimum cost. One of the most important problems of the railways (similarly to the other railways) is the track M&R. Railway track and turnouts are subjected to harshest influences. These influences, both traffic and environment, degrade track geometry and materials in an exponential form. It is very important to determine these degradations in early stages because track condition determines the safety and comfort of rail transport. Premature maintenance or renewals cause extra expenses. Track deterioration due to accumulated work delays can have adverse consequences on line capacity and ultimately on the financial health of the railway. If the average life of track components (rails 55 years, sleepers 25~40 years, fastenings and small components 35 years, ballast 50 years) is considered, theoretically 3 to 10 track renewals are necessary for 100 to 150 years old railways. If a cost analysis is performed, then the considerable expenses for track maintenance and renewal each year are seen clearly (Murthy, T.K.S, Lawrence, L.S and Rivier, R.E, 1987).

Maintenance and renewal of large railway networks require huge amounts of money. For an effective and efficient track M&R process, the data should be condensed. Initially the data are related to basic units of sections. Track recording cars store data for every 100 or 200 m long sections or alternatively on a kilometre basis. The data is then collected into small maintenance sections (MAINS). Measurement, inspections, works carried out and infrastructures are obtained for every MAINS. Finally, the information needs aggregating again into long “route” sections in order to obtain an assessment of the quality or needs of a total route section between major points on the network (Esveld, C., 1989).

## 4. Georaphic information systems (GIS)

GISs are computer-based systems for the capture, storage, manipulation, display, and analysis of geographic information. The multiple functionality afforded by GIS distinguishes it from older technologies. The integration of multiple functionality within one rather seamless environment dispenses users from mastering a collection of disparate and specialized technologies. As it turns out, this aspect is often held by organizations as one of the decisive criteria in their decision to adopt GIS technology because of its efficiency benefits.

The functional complexity of GIS is what makes it a system different from any other. Without geo-visualization capability, the GIS are merely a database management engine endowed with some power to extract meaningful relationship between data entities. Without analytical capability, GIS would be reduced to an automated mapping application. Without database management features, GIS would be unable to capture spatial and topological relationships between geo-referenced entities if these relationships were not pre-defined. What sets GIS apart from other database management systems (DBMS) is not the nature of the information handled. Indeed GIS and DBMS may contain exactly the same information. The difference between the two systems is ``under the hood", namely in the way information is referenced. A DBMS references data by some unique index or combination of indexes. By contrast, information is all about a geographic description of the surface of the Earth in a GIS. Each data record is a geographic event in the sense that it is tied to a unique location defined in a given referencing framework (global, national or local datum). With the spatial referencing of objects, topology of the data can be defined, which in turn enables a host of spatial query operations of objects and set of objects (Thill, J.C., 2000).

## 5. Classification of permanent way M&R

Permanent way maintenance and renewal of any railway comprises the total track length, including all sidings and all points and crossings, and consist of ballast, sleepers, rails and fastenings complete. It requires continuous maintenance for the reasons below (Esveld, C., Profillidis, V.A, 1995, Schramm, G., 1961):

a) The length and alignment of track and turnouts change in the course of time as a result of passing traffic and from other causes.
b) In course of time, the track components wear or lose in strength as a result of traffic or under the influence of time, especially through corrosion of steel and decay of wood and must, therefore, be replaced by new ones after a certain time.
c) Track components have only a limited life and must, therefore, be replaced by new ones after a certain time.

Demands made on carrying capacity and the stability of the track depends on the following circumstances:

1) Axial loads of locomotives and loaded vehicles
2) The weight and intensity of traffic handled by the railways as indicated by the total tonnage travelling over it annually.
3) Speed of trains.

Permanent way maintenance and renewal works are classified into the following sections:

1) Renewals
    a) Track renewal
    b) Sleeper renewal
    c) Rail renewal
    d) Ballast renewal (complete, partial)
2) Replacements
    a) Track replacements
    b) Sleeper replacements
    c) Rail replacements
    d) Ballast replacements
    e) Replacements of switch and crossings
3) Overhaul and maintenance
    a) General overhaul and maintenance
    b) Minor overhaul and maintenance
4) Minor maintenance
    a) Tracks
    b) Turnouts

## 6. Application of GIS for track M&R

In this study, Turkish railways network transferred into GIS environment in order to provide high quality decision support systems (DSS). It was extremely a complex system to transfer all data related network. It requires large amount of data to be available. Thus a track section data contained in various databases and asset management systems (AMS) was transferred into GIS database to be used for the track condition analysis and work planning purposes. This data contains general data, layout and operating data, general data on superstructure and infrastructure, geometry measurements, inspections and other measurements, work history and map data of the railway network on the analysis segment base.

The standard data encompass the following groups of data:

- Administrative data (comprises information about the network and its administrative organisation)
- General data-layout and operating data (curves, loads, speeds, slopes)
- General data on superstructure and infrastructure (ballast, sleepers, rails, structures)
- Geometry measurements (alignment, vertical, twist, cross-level, gauge, quality indices, other user-specific parameters)
- Inspections and other measurements (general condition, ballast condition, fastening condition, sleeper condition)
- Work history (renewals, tamping work history, spot maintenance history)
- Map data (data defining the map(s) of a railway network)

The Universal Transverse Mercator Coordinate (UTM) system provides coordinates on a world wide flat grid for easy computation. The Universal Transverse Mercator Coordinate system divides the World into 60 zones, each being 6 degrees longitude wide, and extending from 80 degrees south latitude to 84 degrees north latitude The polar regions are excluded. The first zone starts at the International Date Line (longitude 180 degrees) proceeding eastward.

In this study, Turkish State Railways network map prepared by Turkish State Railways was transferred into digitalis environment as a raster image. The network map was rectified as being appropriate with a Turkish map having 1/1,000,000 scale, ED50 UTM 36 coordinates on digitalis environment and finally the vector map of the network was obtained by using this raster image (Figure 2).

A model length about 180 kilometres length was divided into analysis segments according to characteristic data of the track mentioned above. These analysis segments are assumed to be homogenous. Especially slopes, curves, type of materials and their ages effected length of analysis segments during diving process. As a result of this process, 180 kilometres track length consisted of 820-unit segments and the average segment length was 220 meters. All processes were realised on GIS environment and connected with a data base included required data for all segments. On GIS environment, it is easy to reach any segments' material type, work history and many only by clicking on it (Figure 3).

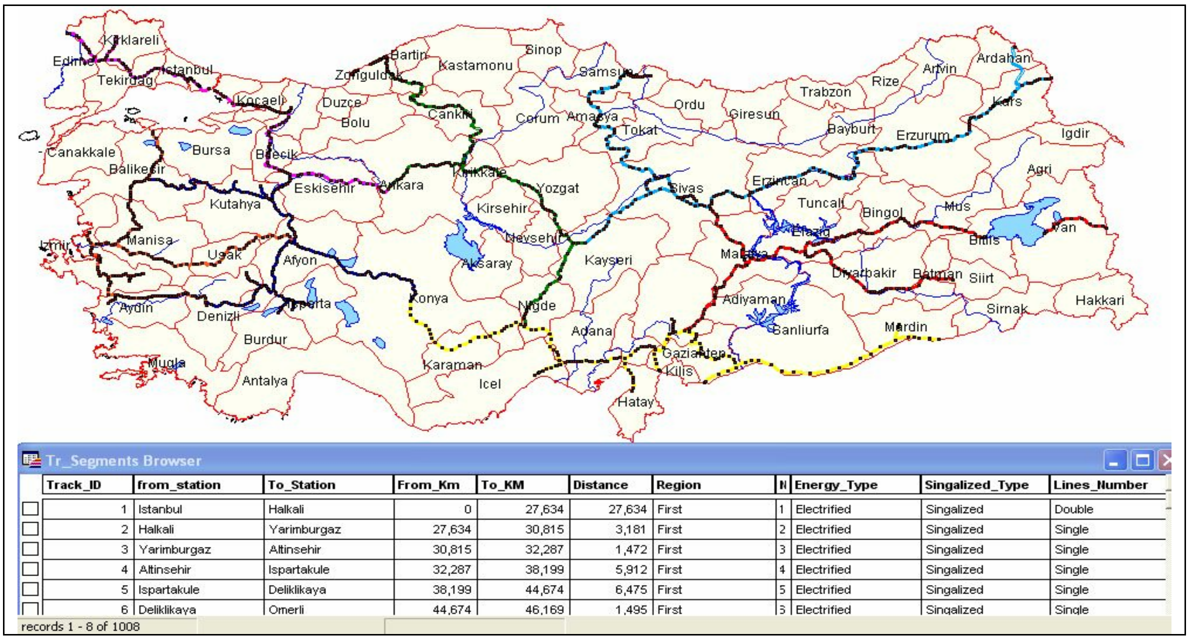



Figure 2. Turkish State Railways networks, stations and section properties on GIS

**MAINS (Maintenance Sections)**

For optimum use of information and control of renewal and maintenance process the data should be condensed. Initially the data are related to basic units of sections. Track recording car data, for example, mostly refer to sections 100 or 200 m long or alternatively are stored on a kilometre basis. Although these units are important for detailed planning of maintenance there are far too many of them for general planning of future policy. The data from these units therefore need collecting into small maintenance sections (MAINS) in order to provide an overview of a route and these would typically be 5 to 20 km long, the actually length probably governed by the distance between stations or junctions. Finally the information needs aggregating again into long “route” sections in order to obtain an assessment of the quality or needs of a total route section between major points on the network. In this study, a model length in the first region of Turkish State railways was divided into 820 MAINS (Esveld, C., 1989).

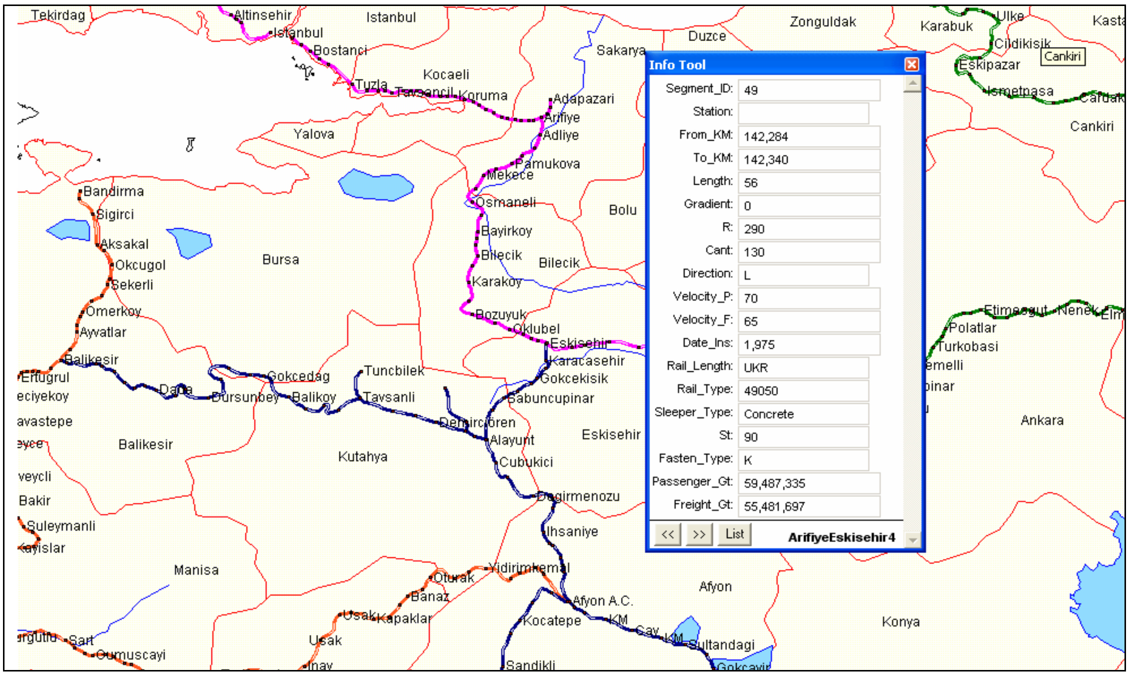



Figure 3. Working track section (Arifiye-Eskisehir) and segment data on GIS

## Quality index and standard deviation

Track recording cars measure the track geometry in graphically. These graphics are transformed into standard deviations. Standard deviations are hard to interpret for non-experts, preferences is given to a QI deduced from the standard deviation. In order to achieve the best possible match, the curves are transformed by changing from standard deviation to QI, via an exponential function according to:

$$QI = 10\left[\frac{QI_{80}}{10}\right]^{\frac{\sigma}{\sigma_{80}}} \qquad (1)$$

This function already satisfies the requirements that QI of 10 applies when σ=0.Via the transformation just one more parameter can be chosen. Quality assessment does require an accurate knowledge of either the very poor or the very good sections. In fact only those close to maintenance intervention level are of interest. On average, 20% of TCDD (Turkish State Railways) per annum is recommended for maintenance and renewal. Although arbitrary, it is obvious choice to assign the same QI, referred to as $QI_{80}$, to the standard deviations at 80% known as $\sigma_{80}$.

The other alternative therefore to apply normalized standard deviations and peak values. In this approach standard deviation σ and peak P should be divided by the corresponding standard. If these standards are referred to as $\sigma_{norm}$ and $P_{norm}$ respectively then the normalized values become:

$$\bar{\sigma} = \frac{\sigma}{\sigma_{norm}} \qquad (2)$$

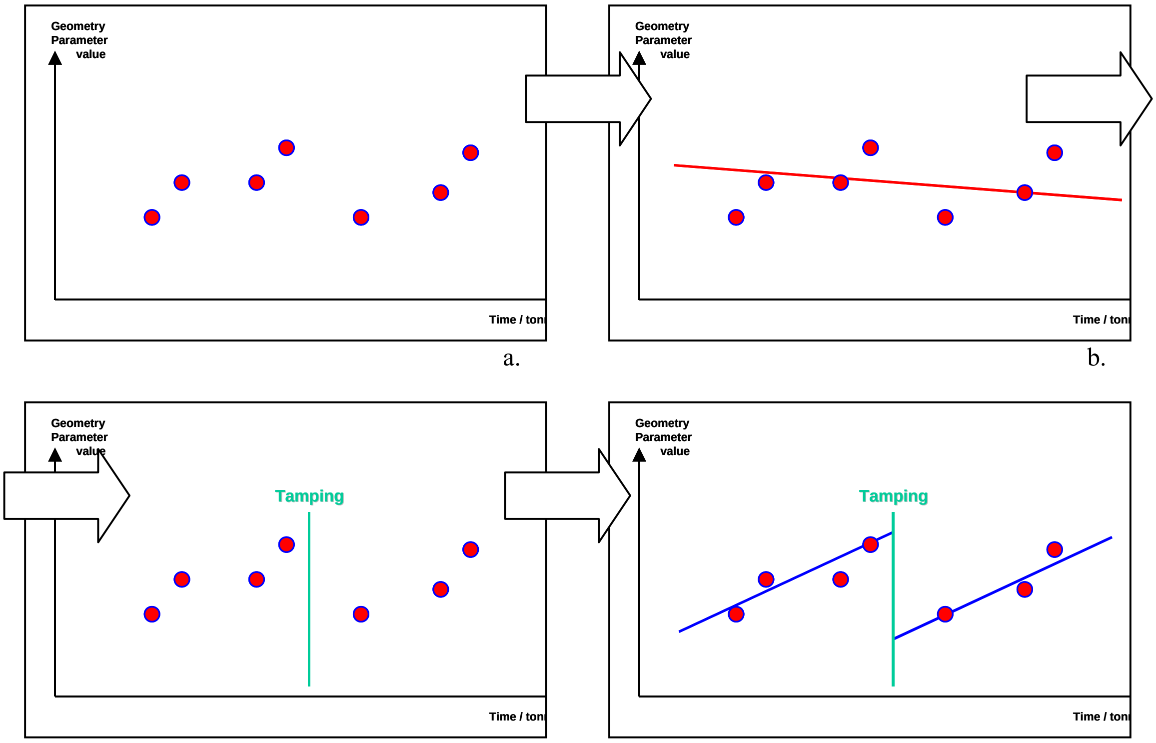
$$\overline{P} = \frac{P}{P_{norm}} \qquad (3)$$

If this is consistent, all the normalized values have, like the quality indices, the same significance. Normalized values less than 1 comply with the standards, whereas normalized values beyond 1 reflect that maintenance action is required. In fact the $\sigma_{80}$ can be regarded as the norm in this approach. The advantage of normalized standard deviations is furthermore that a better resolution is obtained, especially in poor situations.

In this study, the track geometry data measured as graphically by track recording car are transformed into standard deviations. Then QIs and normalized standard deviations of each MAINs were obtained (Esveld, C., 1989).

**Importance of historical data**

The information on the characteristics of track sections and turnouts are important to determine maintenance needs over the short, middle, and long terms. This information must be periodically collected. Having only geometry measurements does not tell much, Figure 4a. Therefore, at least, in order to say whether the measured values are indicating that the track segment in question is good or bad. We need to know the age of that track segment, or/and the accumulated tonnage, speed on that segment, presence of a switch, or level crossing, or bridge on that segment, presence of a curve(s), transition(s), slopes, etc.




c. d.

Figure 4. Importance of having Work-history data

Furthermore, if we try to use the measured data in order to see whether the particular track segment is improving over time or deteriorating, and/or how is it deteriorating (to capture the behaviour of the given track segment). We could attempt to calculate the trend line for the measured values over time. However, as indicated on the Figure 4b, this may indicate that the track was improving over time, which, although wishful, practically never happens in practice. This is again suggesting that we are either misinterpreting the available data, or, which is more likely, still missing some important information on it.

This becomes obvious if we look at the Figure 4c. If we, for example add information about the work history pertaining to this segment, e.g. adding the Tamping work at the moment where it occurred, we are suddenly obtaining a completely different picture, Figure 4d, which is suggesting a completely different behaviour, and which is much closer to the reality. This simple example illustrates the importance of having complete information and moreover, consistently complete and accurate information. Only in that case the information becomes reliable and usable (Jovanovic, S., Korpanec, I., August 2000).

**7. Analysis of data concerning track geometry**

A model length about 180 kilometres length was divided into analysis segments (MAINS). The MAINS choice was intended to enable a study to be made of the effect of:

-the different types of track structure
-the different levels of maintenance operations
-different traffic
-age of the superstructure

The length of the individual MAINS considered is the minimum basic length (average 220 meters). For each basic MAINS, or each uniform track section, the following general information was provided as far as possible:

-track structure (rails, sleepers)
-traffic (total, proportions of passengers and goods traffic, speed)
-layout
-maintenance data

The essential descriptive parameters of the track geometry adopted are the standard deviations of defects in longitudinal level and in alignment measured by the track recording cars. The basic presentation of the data is a time history giving the development of the standard deviation of the defect or the equivalent as a function of traffic or time elapsed, the point of referenced being either the last track renewal operations or the date of first recording (Report D161, April 1987).

These analysis segments are assumed to be homogenous. Especially slopes, curves, type of materials and their ages effected length of analysis segments during diving process. As a result of this process, 180 kilometres track length consisted of 820-unit segments and the average segment length was 220 meters. All processes were realised on GIS environment and connected with a data base included required data for all segments. On GIS environment, it is easy to reach any segments' material type, work history and many only by clicking on it.

As indicated in Figure 5 average quality ($\overline{\sigma}_A$), average improvement due to M&R ($\Delta\overline{\sigma}_{BY}$) and average rate of deterioration ($\Delta\overline{\sigma}/\Delta t$) may be estimated as follows:

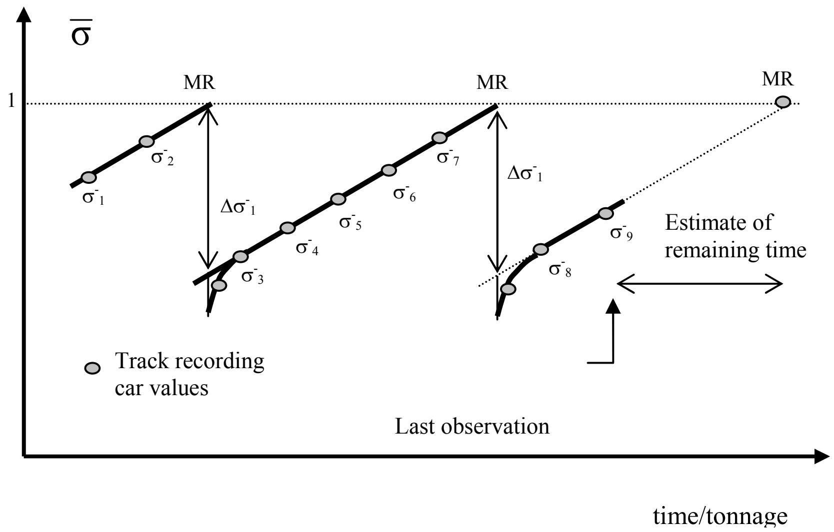



Figure 5. Estimation of the time to M&R using normalized standard deviations

$$\bar{\sigma}_A = \frac{1}{N}\left[\bar{\sigma}_1 + \bar{\sigma}_2 + ......+ \bar{\sigma}_N\right] \tag{4}$$

$$\Delta\bar{\sigma}_{MR} = \frac{1}{N}\left[\Delta\bar{\sigma}_1 + \Delta\bar{\sigma}_2 + ......+ \Delta\bar{\sigma}_N\right] \tag{5}$$

$$\frac{\Delta\bar{\sigma}}{\Delta t} = \frac{1}{N}\left[\frac{\bar{\sigma}_2 - \bar{\sigma}_1}{T_2 - T_1} + \frac{\bar{\sigma}_3 - \bar{\sigma}_2}{T_3 - T_2} + ......\right] \tag{6}$$

In this study, a statistical analysis is performed and rate of deterioration (mm/year) was calculated for every track geometry using the parameters expressed before. Both QI and normalized standard deviations were calculated. The MAINS were grouped accordance to external effects (landslide, flooding etc.) before statically analyses performed. These results were transferred into GIS (Figure 6)

In this study, quality index and normalized standard deviations were transferred into GIS environment for the purpose of M&R analysis. Figure 7 shows QI and NSD values of the MAINS. It is easy to see the future deterioration values of the segments on GIS after the statically analysis performed. M&R managers can see the rate of deterioration on GIS with simple query analysis. Then they can see what kind of M&R works is necessary and they get their precautions for the segments (M-PV7 Rail Recording Railcar User Manuel).

**Rule creation**

After statistic analysis is performed related with track geometry, the rule base of M&R is created. In this task, the maintenance practice and philosophy of the railway company were got into consideration. This task requires existing (default, standard), official regulations and standards pertaining to required track quality, practice in planning track Maintenance and Renewal works etc.

The following rules are created for permanent way maintenance and renewal works accordance the standards written above (ECOTRACK User Manual, Report ERRI D187/DT 299, Report ERRI D187/RP 1):

1) Tamping rules
2) Grinding rules
3) Rail renewal rules
4) Sleeper and fastenings rules
5) Ballast renewal rules

## 8. Conclusion

In both industrialised and developing countries, one of the main problems of railway companies is regarding track maintenance and renewal (M&R). In today's environment, Turkish railways do not possess any serious working plan for track. The gateway to economic development and, subsequently, a healthy economy, transportation infrastructure represents one of the largest and most critical investments made in any nation, at any stage of development. Similarly, for many firms in the transportation industry, profitability and a strong competitive position depend on a safe and reliable system. GIS can be used to determine the location of an event or asset and its relationship or proximity to another event or asset, which may be the critical factor leading to a decision about design, construction, or maintenance. The aim of this paper was to demonstrate the capabilities of GIS in analyzing the track condition and providing consequent decision support regarding permanent way M&R works.

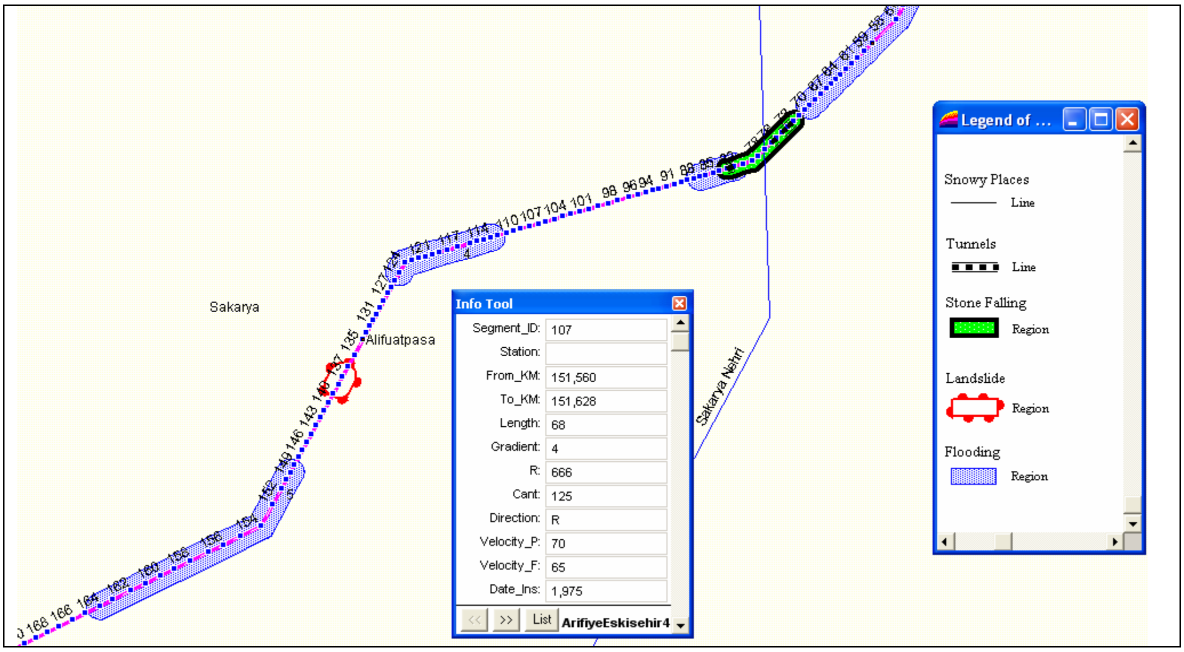



Figure 6. External factors on GIS

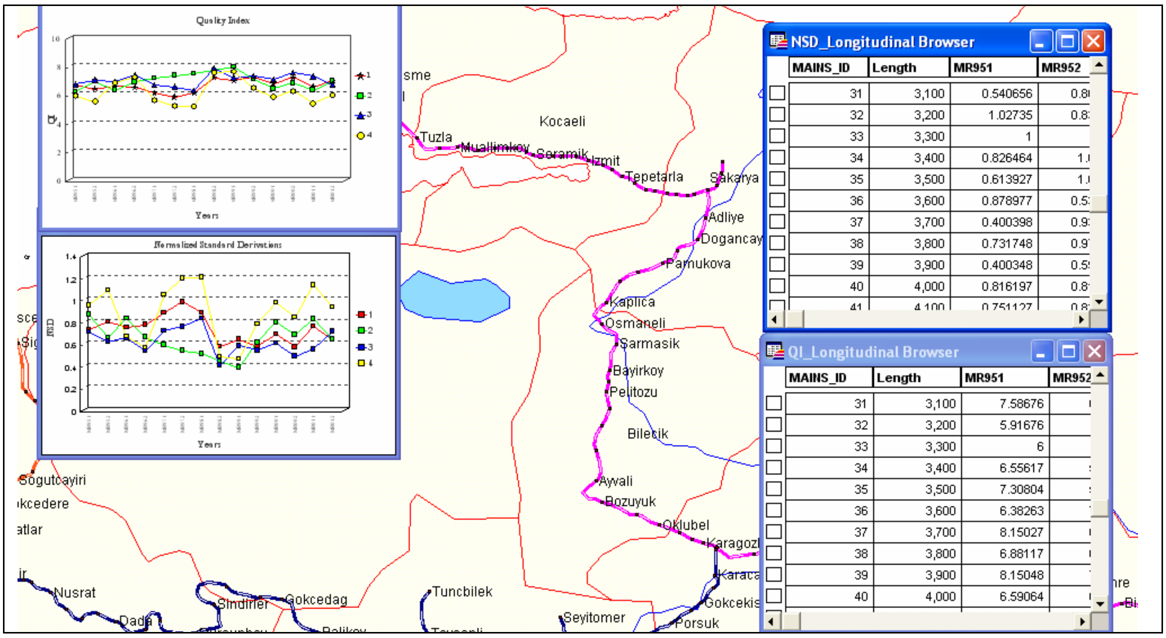



Figure 7. Quality Index and normalized standard deviations of the MAINS on GIS

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